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CHANNEL RAILWAY REPORT





OLD COUNCIL OF
BEND
MICHIGAN



OLD FURNACE TIER

1874

NEW YORK

Channel Railway.

DESCRIPTION

OF A PROPOSED

CAST-IRON TUBE

FOR CARRYING A

RAILWAY ACROSS THE CHANNEL

BETWEEN THE COASTS OF

ENGLAND AND FRANCE.

BY

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CHANNEL RAILWAY.

IN a recent Report to the Board of Trade on the means of communication with India and the East, Captain Tyler — after comparing the advantages of the various routes, by Marseilles, by Mont Cenis, and by the Brenner Pass, states—that they “will, “however, themselves be only provisional, pending “the advance of railway communication through “the south-east of Europe, and through the west “of Asia. The lines by Constantinople and the “Euphrates Valley, and over the Greek Frontier to “Cape Sunium, so near to the Suez Canal, have yet, “in process of time, to be constructed; and the hope “of the Indian traveller of the next generation, “chimerical as it may appear to many at present, “must be nothing less than to pass dryshod from “London to Bombay,—through a submarine tunnel “from Dover to Calais,—through Europe by railway,—over the Bosphorus by a bridge,—and forward “by railway down the Euphrates Valley, and round “the Persian Gulf, to Bombay.”

One of the links in this chain of communication it

is the object of the proposal, described in the following pages, to supply, and to enable the continental traveller to pass, in the words of Captain Tyler, "dryshod" beneath the Straits of Dover. Time was when such a proposition would have been regarded by all as chimerical; but so frequently has the possibility of accomplishing the object been before the public, and so often has it been discussed by men well able to form a sound judgment upon the question, that it has ceased to possess the quality of novelty, and may now be quietly discussed with relation to its practicability and the mode of its accomplishment.

The advantages which would accrue from a continuous railway communication between England and France are great beyond any possibility of estimate. They have been dwelt upon in graphic language by many writers upon the subject, and by none more so than the late Mr. James Chalmers, who, in 1861, and again in June, 1867, advocated the construction of a submarine tube for the passage of railway trains. They are summed up in an article in the *Mechanics' Magazine*, written in February, 1862, by Mr. Cook, of Whitehaven, in his remarks upon Mr. Chalmers' proposition, as follows:—"As to the commercial value of the undertaking, no one who knows anything of the continent and its productions, and can appreciate the facilities for a highly remunerative traffic which the Channel Railway would open out, can doubt of

" its success as a paying speculation, if no more than
 " twelve millions be expended in its construction.
 " The Channel Railway, for its peculiar traffic, could
 " have no competitor. Having been entrusted for
 " several years with the active part of the manage-
 " ment of the South-Eastern Railway's continental
 " business, I am able to form some idea of the
 " impetus which would be given to foreign travel
 " and trade on both sides of the channel, were this
 " communication made; but I believe the most san-
 " guine estimates would be as far exceeded in this
 " case as they were in the case of the first railways.
 " The traffic, too, would be of the best paying
 " description; not minerals at a half-penny per ton
 " per mile, but first-class passenger traffic, and light
 " valuable merchandise, mails, bullion, parcels, &c.,
 " and this, not to and from France alone, but to and
 " from the most distant parts of Europe. The new
 " commercial treaty with France has already more
 " than doubled our exports. What would they be
 " were this railway completed, and that treaty
 " changed to absolute free exchange of products,
 " which would certainly follow?" Captain Tyler, too,
 in his Report already referred to, and in remarking
 on the three routes on which he specially reported,
 says:—"For the present, the above three practicable
 " routes are all that need occupy our attention.
 " They may appear to be rivals to one another, and,
 " as regards the two latter, for a through traffic yet
 " to be increased, or even created. But regular

“ means of communication will infallibly bring to
 “ each of them passengers and goods, on which, as
 “ yet, we do not calculate. Having regard to the
 “ interests involved, to the population and the
 “ countries to be served, to the commodities to be
 “ exchanged, there can be no doubt, in pursuance of
 “ all previous railway experience, that offering, in
 “ apparent competition with one another, increased
 “ facilities, they will, by facilitating additional travel-
 “ ling, increasing knowledge, and inducing commerce,
 “ contribute to the advancement rather than to the
 “ detriment of one another. There will, in time, be
 “ enough passing between the great East and the
 “ busy West to support more than three lines of
 “ through communication.”

If this be true, with reference to three lines of
 communication, how much more forcible will be the
 argument in favour of one communication between
 England and the Continent, through which nearly all
 the goods and passenger traffic to and fro may be
 expected to pass.

From time to time various proposals for effecting
 the object in view have been before the public—by a
 tunnel to be driven beneath the bed of the sea,
 through the chalk, which is supposed to be continuous
 —by submerged roadways and tubes—by large ferry
 boats carrying trains on board—and by bridges to
 be carried on piers formed on islands to be sunk
 in the Straits. To the latter proposition there are so
 many obvious objections, that it is hardly necessary

to discuss its practicability, although a project of this nature, strange to say, is now attracting attention in Paris.

A large ferry-boat, of great length and breadth, large enough to receive a whole ordinary train on board, and driven at high speed by powerful engines, would unquestionably be a material improvement upon the present miserable means of conveyance. Such boats cannot, however, be employed, except by the construction of special harbours on each coast, which would be works of difficulty and expense. However successfully such a scheme might be worked out, the annoyance attending a sea passage in rough weather, although mitigated, would not be removed; and it would frequently occur in the course of the year, that the traffic would be interrupted by fogs and bad weather. Under any circumstances, ferry-boats across the channel would be very far from a complete and perfect railway communication.

With reference to a tunnel, it has been proposed to drive one of ordinary size for a double line of railway, which shall descend by a gradient of 1 in 60 on each side of the channel to a depth of about 270 feet below the bed of the sea. The total length of the tunnel would be 30 miles, of which 22 would be beneath the sea.

The uncertainty of the strata in the bed of the channel, and the dangers to which any tunnelling operations for some 20 miles under the sea would be subject in the event of meeting with open strati-

fication or dislocated material, are such as would in all probability deter capitalists from entering on so hazardous an enterprise, and would baffle and overpower both engineering skill and all mechanical appliances. Still the project of a tunnel is entertained and advocated by engineers of great standing and reputation, and must only be discarded on a better system being proved to be available.

An address having been presented to the Emperor of the French in favour of the project of a Tunnel, signed by many Peers, Members of Parliament, and other persons of importance, His Majesty appointed a commission to inquire into that project. The report of this special commission has recently appeared, and the result of the inquiry may be briefly summed up as follows:—That the driving of a submarine tunnel in the lower chalk is an undertaking which presents reasonable chances of success, but that its execution is subject to contingencies which may render success impossible; that these contingencies may arise from particularly treacherous ground, which, however, they think improbable, or from an influx of water in a quantity too great to be mastered; that in the incomplete state of the preparatory investigation, they will not fix upon any figure of expense, or probable time, which the execution of the work would require. The matter was afterwards referred to the General Council of Ponts et Chaussées, presided over by the Minister of Public Works; but they were unable, “upon the documents submitted to them, to decide

“upon the probability of success of the tunnel under the channel,” and considered that “if from political considerations the undertaking should be considered useful, the Governments should follow up the investigation at their own expense.”

The distance to be crossed, and the cost to be incurred, require that the mode to be adopted shall be absolutely free from *serious* doubt and risk, and shall be as evidently capable of accomplishment as the most ordinary mechanical operation. Some degree of uncertainty must exist in every contrivance and speculation; but, unless a scheme can be proposed which will be free from all doubt and objection so far as human knowledge and foresight can extend, it will hardly deserve, and will probably not receive, the support of the public.

None of the proposals for constructing submarine tubes, which have hitherto been brought forward, are free from serious objections, both on the score of difficulty of construction and the dangers which would attend the operations as proposed. In that now about to be submitted, every possible contingency which could present itself to the minds of the designers, has been considered and endeavoured to be provided for; but it may be that competent men will see objections and difficulties which have escaped attention and consideration, and which may require some modification to meet or overcome.

Mr. Chalmers' plan was received with some favour by the public, and he deserved great credit for the

careful consideration he had bestowed upon it. He proposed to construct a tube of wrought iron, in sections of 300 or 400 feet in length, and then to submerge them, drawing them together "by means of" "endless chains passing round pulleys or drums attached to massive anchor boxes on the bottom of the Channel," and by various processes, which he describes, to make a permanent connection when at the bottom of the sea. Neither these operations, nor others which were necessary for completing the whole tube, appear to us practicable, and they would in any case, even if practicable, be attended with so much risk of failure, and so much danger to the men employed, that the scheme, though ingenious, would probably fail in obtaining support, or fail in execution if attempted.

Our object has been to devise a scheme by which all difficulties of operating in water should be avoided. We propose to lay a tube of cast iron on the bottom of the sea, between coast and coast, to be commenced on one side of the channel, and to be built up within the inside of a horizontal cylinder, or bell, or chamber, which shall be constantly pushed forward as the building up of the tube proceeds. This description will be better understood by an examination of the drawings attached. The bell or chamber within which the tube is to be constructed will be about 80 ft. in length, 18 ft. internal diameter, and composed of cast-iron rings 8 inches thick, securely bolted together. The interior of the bell will be bored out

to a true cylindrical surface like the inside of a steam cylinder. The tube to be constructed within it, will consist of cast-iron plates in segments 4 in. in thickness, connected by flanges, bolted together inside the tube, leaving a clear diameter of 13 ft. when finished. Surrounding this tube and forming part of it, will be constructed annular discs or diaphragms, the outside circumference of which will accurately fit the interior of the bell. These diaphragms will be furnished with arrangements for making perfectly water-tight joints for the purpose of excluding sea water and securing a dry chamber, within which the various operations for building up the tube, and for pressing forward the bell as each ring of the tube is added, will be performed. There will always be three and generally four of these water joints contained within the bell. A clear space between the end of the tube and the end or projecting part of the bell of 36 ft. will be left as a chamber for the various operations. Within this chamber, powerful hydraulic presses, using the built and completed portion of the tube as a fulcrum, will, as each ring is completed, push forward the bell to a sufficient distance to admit the addition of another ring to the tube. The bell will slide over the water-tight joints described, one of which will be left behind as the bell is projected forward, leaving three always in operation against the sea. The weight of the bell and of the machinery within it, will be a little in excess of the weight of water displaced, and therefore the only

resistance to be overcome by the hydraulic presses when pushing forward the bell, is the friction due to the slight difference in weight and the head or column of water pressing upon the sectional area of the bell against its forward motion. In like manner, the specific gravity of the tube will be a little in excess of the weight of water which it displaces; and in order to obtain a firm footing upon the bottom of the sea, the tube will be weighted by a lining of brick in cement, and for further protection will be tied to the ground by screw piles, which will pass through stuffing boxes in the bottom of the tube. These piles will, during the construction of the tube within the bell chamber, be introduced in the annular space between the outside of the tube and the inside of the bell, and will be screwed into the ground as they are left behind by the progression of the bell. The hydraulic presses and the other hydraulic machinery, which will be employed for lifting and fixing the various segments of the tube, will be supplied with the power required for working them from accumulators on shore, on Sir William Armstrong's system, and the supply of fresh air required for the sustenance of the workmen employed within the bell and within the tube will be insured also by steam power on shore. As the tube is completed, the rails will be laid within it for the trains of waggons to be employed in bringing up segments of the rings as they may be required for the construction of the tube, and for taking back the waste water from the hydraulic presses, or any water from leakage during the construction.

The tube will be formed of rings of 10 feet in length, each ring consisting of six segments, all precisely alike, turned and faced at the flanges or joints, and fitted together on shore previous to being taken into the bell, so that on their arrival the segments may, with perfect certainty and precision, be attached to each other. Every detail of construction has been designed, and so far as we can see, no contingency has been left unprovided for. The possibility of injury by anchors or wrecks, or submarine currents has also been investigated. The tube when laid will be secure from all dangers arising from such causes.

The building of the tube will be commenced on dry land above the level of the sea, and will be gradually submerged as the tube lengthens. The operations on dry land will be attended with more difficulty than those under water, but all these circumstances have been carefully considered and provided for. The rings forming the tube will be made by special machinery, to be expressly constructed for facilitating the work and economising the cost. This machinery is all designed and specified. The first half mile will test the feasibility of construction, for that will have to be built both above and under water. When once fairly under water, the progress should be rapid, and it is estimated that the whole undertaking may be easily completed in five years from the commencement.

The precise line to be taken betwixt the English and French coasts can hardly be determined without

a more minute survey of the bottom of the Channel than at present exists. It will probably be between a point in close proximity to Dover on the English coast, and a point in close proximity to Cape Grisnez on the French coast. From an examination of the Admiralty Charts, and of such information as at present exists, the sea bed on this line appears to be the most uniform in level, and, while free from hard rocks and broken ground, to consist of coarse sand, gravel and clay. The average depth of water is about 110 feet, the maximum about 200 feet. On the line suggested the water increases in depth on both sides of the Channel more rapidly than elsewhere, although in no instance will the gradient be more than about 1 in 100. The tube, when completed, will occupy about 16 feet in depth above the present bottom of the sea. Up to the point on each shore at which the depth of water above the top of the tube would reach, say 30 feet at low water, an open pier, or other protection, would have to be constructed for the purpose of pointing out its position, and of preventing vessels striking against the tube. These piers may be rendered subservient to harbour improvements. The tube at each end would gradually emerge from the water, and on arriving above the level of the sea would be connected with the existing railway systems, so that the same carriage may travel all the way from London to Paris, or, if Captain Tyler's anticipations be realised, all the way from John O'Groat's to Bombay.

The distance across the Channel on the line chosen is about 22 miles. The tube as proposed is large enough for the passage of carriages of the present ordinary construction, and to avoid the objections to the use of locomotives in a tube of so great a length, and the nuisance which would be thereby created, and taking advantage of the perfect circular form which the mechanical operation of turning, facing, &c., will insure, it is proposed to work the traffic by pneumatic pressure. The air will be exhausted on one side of the train and forced in on the other, and so the required difference of pressure will be given for carrying the train through at any determined speed. Powerful steam-engines, with the necessary apparatus for exhausting and forcing the air into the tube, will be erected on shore at each end; and supposing one tube only to exist, the traffic will be worked alternately in each direction.

This system of working the traffic will secure a constant supply of the purest air, which will accompany every train; and sitting in a train on its passage through the tube, will be as pleasant and agreeable, in respect of ventilation, as sitting in the open air on the sea side or in the best ventilated drawing room.

By this system of working and by adopting the best description of materials and rolling stock, there would scarcely exist the chance of accident — no collision could take place. There would never be foul air within the tube to annoy the passengers or to hinder the traffic by the necessity of removing the

tainted air before another train could pass through. The pneumatic system, though hitherto tried on a small scale only, is undoubtedly one which, by the proper choice of means, can be certainly and easily, as well as cheaply worked, and in so long a tunnel, we believe it to be in every way preferable to locomotive power, although that also could be adopted.

It has been found by calculations, that, for moving a large amount of tonnage and a great number of passengers, the most economical arrangement will be to send combined goods and passenger trains through the tube at 20 miles an hour, with occasional express trains at 30 miles an hour. Thus, an ordinary or slow train would occupy about 66 minutes in the transit, and a quick or express train about 45 minutes. In this way the tube, if fully worked, would permit the passage of 16 ordinary slow trains (8 each way), and 6 express trains (3 each way) each conveying both goods and passengers—about 10,000 tons of goods per day, or upwards of 3,000,000 per annum; and 5,000 passengers, or nearly 2,000,000 per annum—might be taken through, or a less amount of goods and a larger number of passengers, or *vice versâ*, if circumstances rendered other proportions necessary or desirable.

The horse power required for working the traffic with the above number of ordinary and express trains, will be, on the average, 1,750 indicated, or about 400 nominal horse power at each end.

The journey from London to Paris may be easily performed in eight hours, or less, without any break or change of carriage, and the annoyance, delay, and interruption, attending a sea passage would be altogether avoided.

The estimated cost of the whole undertaking, including the stations and approaches at each end, the engine power and machinery, the interest of outlay during construction and engineering superintendence, with a large margin for contingencies, is £8,000,000.

What the traffic would be, to pay interest on this outlay and working expenses, it is difficult to estimate. Mr. Chalmers, in his pamphlet, states that "between 1820 and 1830, in the good times of sailing packets, the number of travellers between England and the continent did not exceed 80,000 per annum; the establishing of a regular steamboat service raised the number, in 12 years, to 350,000; and since the introduction of railways it has risen to upwards of a million. This great increase is not to be attributed to the increase of the populations, but mainly to these improvements; and the effects that would result from the completion of this work would be even greater than were produced by those two important revolutions in locomotion, which, respectively, raised the figures from 80,000 to 350,000, and from the latter to upwards of a million." Mr. Chalmers, himself, estimates the total annual revenue at £1,300,000, assuming

however, as one of the items of his calculations, only 2,500 tons of freight daily. The tube is capable of conveying, on the pneumatic plan of working the trains, with ease, 10,000 tons of goods per day, and we may reasonably calculate that the amount of traffic will be limited only by the power which may exist of passing it through the tube.

On the question of traffic, we are again indebted to Captain Tyler. In a report to the Board of Trade "On the improvement of the means of communication between England and France," and on the existing state of the French and English coasts, with reference to the annual channel traffic, he states as follows:—"Omitting from consideration the ports of Hamburg, Rotterdam, Antwerp, and Ostend, the passenger traffic between England and France for the year 1868 amounted to 309,479 altogether; 141,633 passengers having travelled by Calais, 109,006 by Boulogne, 41,371 by Dieppe, and 17,469 by Havre. A large proportion of these, namely, 46,411, crossed the Channel in the month of August, as against 12,946 in January, and 13,514 in February. In the year 1867, of the Paris Exhibition, the numbers were 454,350 altogether; 199,837 having travelled by Calais; 146,226 by Boulogne; 86,914 by Dieppe, and 21,373 by Havre. Of these, 84,684 crossed in August, against 13,163 in January, and 13,721 in February. In addition to the ordinary annual increase, which is considerable, there would natu-

“rally be a very large augmentation in these numbers, if better arrangements were made for crossing the Channel.”

The annual working expenses will consist of maintenance, which will be light, of the cost and wear and tear of the pumping engines, and of the ordinary expenses of management, the whole of which would be most amply covered by £150,000, which, deducted from the lowest computation which has been made of the probable returns, would leave considerably more than one million sterling per annum, available for dividend upon the outlay involved, or about 14 or 15 per cent.

This brief description and the drawings attached will be sufficient to give to the ordinary reader and the public a general idea of the proposal. Those who care to investigate the question more closely will find every point separately and elaborately explained in the Appendix; our object being to give the fullest information, and to invite the most searching scrutiny into the soundness and accuracy of our proposal and the statements we have made.

It would be easy to enlarge on the advantages to the whole world which such a bond of union would bring about, especially to the two great nations which would be thereby most intimately connected; but in a dry and scientific description of the means by which this important work of communication is proposed to be accomplished, such language would be out of place. Let it be proved to be a prac-

licable undertaking, and the best or most promising which has been suggested, and it may well claim the support and the material assistance of the Governments of England and France, as well as of all the nations of Europe.

APPENDIX.

FIRST SECTION.

No. 1.

Constructing parts of the Tube and of the Bell.

THE Railway Tube across the Channel will be made of cast-iron ; it will be cylindrical, formed of rings ; and these again will be composed of segments. The elementary parts of the Tube are therefore segments of a circle in the shape of heavy cast-iron plates, with flanges for bolting the segments together, to form in the first instance the rings ; and with other flanges for attaching the rings to each other in succession, to form the Tube.

All the rings of the Tube for about 21 miles will be of identical form and size ; the whole Tube, with the exception of a short length at each shore end, will therefore be composed of segments similar in every respect. They will be nowhere less than 4 inches thick, at their flanges from 4 to 6 inches, and in the radial direction of the flanges about 14 inches ; the length of each segment will be 3 metres, or about 10 feet, its weight about 10 tons, and the weight of one cast-iron ring will be about 60 tons.

Fig. 4 shows a section of the plates at their junction with one another along the Tube ; Fig. 5 represents a section across the Tube. These sections are drawn to a scale of $\frac{1}{10}$ th full size. The diameter of the Tube clear inside, when finished, will be 4 metres, or about 13 feet.

The segments will accordingly be heavy castings about 10 feet long, $7\frac{1}{2}$ feet wide and 4 inches thick, weighing 10 tons each. These castings will be simple, of uniform dimensions, and will be of the best grey metal. They will be delivered at the works near Dover, and will here be subjected to further mechanical operations, such as planing, turning, facing, &c. These operations will be more conveniently conducted at the mouth of the Tube, in order to meet promptly any requirements during the process of

building. It will also increase the facility of superintending the construction of details.

The first mechanical operation to which the castings at the works will be subjected, is the planing along their straight longitudinal flanges, along *a, b, c*, Fig. 5. Each segment has two such flanges 10 feet long, 14 inches wide, with a groove about midway. Both these flanges will be planed simultaneously with about 3 cutters at each flange. In some of the plates, according to their position in the ring, a groove for the permanent rails will have also to be planed simultaneously with the flanges, employing an additional number of tools. The whole operation of planing one segment by a machine specially constructed for the purpose may thus be completed in about 3 hours; and as with the proposed progress of building the Tube 60 segments will daily be required, and as each planing machine will, on the average, daily turn out 3, so the number of planing machines required at the works will be about 20.

The segments having been planed along their straight flanges, bolt-holes may now be drilled into them by ordinary drilling machines, which having been made, they may now be bolted together to form the rings.

The next important operation will be the turning and facing of these rings along their circular flanges, along *a, b, c*, Fig. 4. In order to make the rings truly cylindrical and concentric upon all their flanges, facings and grooves, and to insure promptness and rapidity of operation, it will be a main condition that all of them shall be turned and faced simultaneously at one operation. These heavy rings, of about 60 tons weight, to be turned in a particular way, will require special lathes, to be constructed exclusively for the purpose; they will have to be turned with their axes in a vertical position; the facing plate of the lathe will therefore form a large horizontal turntable to which the rings may be firmly bolted. The upper and lower flange, and the groove and facing on the annular rib midway—will be turned at one operation. The number of cutters will be about 20, according to the mode of turning adopted and preferred for the purpose; all, however, cutting simultaneously, and so completing the turning of the ring in about 4 hours. Allowing one hour to take off any irregularities which a change of cutters may produce on the surface allotted for each tool—and one hour for fixing and removing a ring by hydraulic cranes—then, on the average, one ring will be turned out by one lathe in about 6 hours; and inasmuch as with the proposed progress of building the Tube, 10 rings will daily be required, so the number of lathes of special construction at the works will have to be about 5.

In the operations of turning or planing it is not usual to

employ more than one or two cutters at a time. The reason for this is obvious. If provision were made for employing a number of tools in turning or planing parts of a machine, the great variety of these parts in form and size would but rarely admit the use of the additional cutters, and thus the lathe or planing-machine would be unnecessarily complicated by arrangements but seldom of any use; and further, for every additional tool contemplated in the use of the machine, additional strength must be given to all its parts, adding thereby greatly to the original cost of the machine, because the dimensions and thicknesses of metal are mainly regulated by the strain which the tools will bring on its various parts. Exceptional circumstances require exceptional treatment. In the present case we have to operate upon segments and rings all of identical form and dimension; therefore, every contrivance useful in producing one will be useful in producing all; the size and weight of the parts to be operated upon are also exceptionally large, consequently the size and the cost of the machines to be employed for producing the rings of the Tube will almost wholly be determined by the weight and size of the segments and of the rings. The additional strength required to meet the strains produced by the shaping tools, is but small in comparison to the strains produced by the weight and size of the parts to be turned and planed. We must, therefore, take advantage of the circumstance, and having a heavy and strong machine firmly to hold the parts to be turned and planed, we shall usefully employ several shaping tools, and thereby reduce the number of lathes and planing machines of the establishment.

We dwell upon these points, because to those not fully initiated in the details of mechanical operations, it may appear exceptional to employ a number of shaping tools all cutting simultaneously, and may perhaps think it a questionable proceeding. The experienced mechanic will see the point at a glance. It is not only the way of producing the article most readily and quickly, conducing to regularity and uniformity of workmanship, but it insures more valuable results than these—it insures accuracy and truthfulness almost independently of the ability of the workmen employed; for serious inaccuracy of workmanship, resulting from want of care or ability, is chiefly favoured by a change in the position of the article to be operated upon, by refixing, shifting, and the like, all of which sources of errors are obviated by completing the mechanical operations of turning, planing, &c., in one position of the segment or of the ring.

We further dwell upon the mechanical part in the construction of the Tube, because it may at first sight appear to involve a larger expense than desirable. We have shown the probable number of the principal planing and turning-machines required at the esta-

blishment, and the tonnage which they may daily finish of the construction. It will thus appear to the reader, and to those initiated in these matters it will be demonstrated, how small the additional expense per ton is, which the mechanical operations under these circumstances involve, and which insure almost mathematical accuracy in the construction of the Tube. Half a dozen powerful lathes, two dozen planing-machines, and a dozen drilling and smaller tools will daily turn out 600 tons of the Tube.

Each of these powerful lathes will be worked by a separate engine, and hydraulic lifting machinery, and will form a small establishment of its own. The designs and the specification for the construction of these various machines have been completed.

In the consideration of the proceedings to be adopted for the various mechanical operations, we must bear in mind that the ultimate result to be gained is the construction of a great number of similar parts; the number of rings required exceeding 10,000; these again are to be formed of segments of identical shape and dimensions, their number exceeding 60,000; that all the arrangements of plant and machinery at the works should be made with a view for producing readily these plates and rings in the most perfect and economical manner, and in the shortest possible time.

The Bell within which the finished segments are again to be bolted together to form the rings of the Tube in their final position, will be a cylinder about 80 feet long and 18 feet diameter. It will be formed of eight separate rings, with a cover at one end. Each of these rings will be 10 feet long, 18 feet diameter in the clear, and 8 inches thick; six of which will be bored out to form a true cylindrical surface. These rings might also be formed of two or more segments, as may be more convenient; but it is proposed to cast them in one, and although, very heavy castings, the number required being small, it will be preferable to have them cast in one for this purpose. The rings of the Bell will be turned at their flanges by the lathes above described for turning those of the Tube. The construction of these lathes, or of some of them, will be made with a view for finishing also parts of the Bell.

No. 2.

Constructing the Railway Tube in deep water on the bottom of the Channel.

We will assume that part of the Tube had been constructed and finished on the bottom of the Channel, and we will describe the mode by which an additional length of the Tube may be built in deep water. Whatever portion of the Tube may be considered

as built, its foremost point will, in deep water, always be covered by the Bell. Thus, at whichever point of the proposed line across the Channel the construction of the Tube may be considered, its last half dozen rings are always within the Bell, which, as the foremost part will, as it were, form the head of the Tube. The Bell will slide over annular discs, which form part of the rings of the Tube. These annular discs are tubular in section, and are performing several important offices:—1st. They guide the Bell, the inside of which they closely fit, and by means of a hydraulic joint introduced into a groove of the disc at its circumference touching the Bell, they form a watertight junction, and so exclude the water from entering the Bell, within which there will be ample room for the machinery, under the guidance of a few workmen, to take hold of, lift, place, and fix the segments in their various positions. 2nd. They form annular spaces between outside the Tube and inside the Bell; into these, screw piles may be introduced wherever required, the cast-iron head of a screw being temporarily attached to the segments; Piles may thus be used wherever desirable without any inconvenience or delay. 3rd. These annular discs of tubular section, form girders round the Tube and greatly strengthen and stiffen the segments with which they are cast in one. The segments overlap each other at every succeeding ring—the junction of two coming midway of a segment of the preceding or succeeding ring; accordingly, these tubular girders tie over the junctions and make the Tube greatly more resisting against compression than if it were cast in one without discs.

Having now given an outline of the general proceeding of the construction of the Tube in deep water, we shall now readily follow the principal section Fig. 1, showing the end of the Tube, the Bell, and the machinery by which the Tube is to be constructed within it; the hydraulic presses, to move or push forward the Bell, as its fitting chamber is being filled by the completion of another course of ring, &c., &c.; merely observing, that we shall consider the progress of these works on the bottom of the Channel, in constructing the last mile of length, which on the proposed line would be about 20 miles from the shore from which the construction of the Tube had been started.

Whatever the difficulties in building the Tube across the Channel may be, great or small, these difficulties will be most felt and will be greatest in the construction of the last mile, the completion of which is more important than that of the first, because of the labour and money already employed in the various operations of the preceding 19 miles. It is, therefore, at the last mile that we propose to describe the various operations in deep water on the bottom of the Channel, considering the preceding length of the Tube completed,

Referring to our principal section, Fig. 1, we have before us the end of the Tube, covered over by the Bell, which we will assume to be at the commencement of the twenty-first mile. In the foremost part of the Bell are shown the hydraulic presses, four in number, of which two only are seen in elevation. In this chamber of the Bell there is also a platform for the Superintending Engineer, and for small machinery. The length of the platform is about 20 feet, and it is about 18 feet wide, affording ample room for various machinery and for the convenience of the Engineers; it is enclosed between the cover of the Bell and a cast-iron disc (*A*), bolted at its circumference to a flange of the Bell. This separating disc has two doorways, which lead to the platform of the press-chamber, from which the various operations of building the Tube may be superintended. The disc (*A*) serves also as a support of the main square shaft (*B*) keyed to the centre of the disc. This shaft reaches across the fitting chamber of the Bell to within the first couple of rings of the Tube, and there, it is resting upon a semi-circular frame (*C*) shown in elevation, which may slide within the grooves intended for the permanent rails, upon two iron bars (*a*). The frame is also shown in side elevation (Fig. 2), with the bars (*a*), and with two other bars (*b*) midway the tube, to steady the frame in a lateral direction during the various operations.

On the main shaft (*B*), Fig. 1, there is a turntable (*D*), the various functions of which will presently be explained. The table (*D*) is sliding on the shaft (*B*), between the frame (*C*) and the disc (*A*). The boss (*c*) of the table is in two parts, the inner is a cylinder with a square hole along its axis, accurately fitting the main shaft. Upon the cylindrical surface of this inner boss, the boss proper of the table is turning. On each side of the boss (*c*) there is a cylinder (*d*) cast in one with it, and in each cylinder there is a piston or ram (*e*), worked by hydraulic power. Both these pistons are firmly keyed to the table (*f*). When, therefore, they are moved within the cylinders, the table (*f*) will get nearer or further the main shaft (*B*). In Fig. 1 the table is shown in its furthest position from the centre of the main shaft, which is also the centre of the Tube and of the Bell.

An internal wheel (*g*) is also bolted to the boss (*c*) of the turntable; it is worked by a pinion within the wheel. This pinion is held in position by a bearing forming part of the first described central part of the boss. In sliding the table along the main shaft (*B*), the shaft (*h*) of the pinion will also slide parallel with it through a bearing in the disc (*A*). The shaft (*h*) is worked by gearing (*k*) and a crank (*l*), the latter being turned by a pair of small water-engines within the press-chamber erected under the platform. Whenever, therefore, water from the accumulators on

shore is admitted to these engines, the pinion will be turned in the direction required, and the large internal wheel (*g*), forming part of the boss, and with it the table (*f*), will revolve round the main shaft to any extent and in either direction.

The sliding turntable is shown in an exceptional position in Fig. 1, viz., putting in the last segment of the ring (*E*), of which five are already bolted to the Tube. This position of the machinery was selected because it is most unfavourable for the Bell in reference to the Tube. To place the last segment of a ring, the Bell must be pushed forward the whole length of another course, for, the sixth segment of any ring cannot be placed in the same way as the other five, it being wider at its outer circumference than at its inner, and will not pass through the opening left by the other five already in position.

To place or fix the last segment of any ring, the bell must be moved forward by the hydraulic presses for a length of about 10 feet, being that of another course of ring. The sixth segment is then raised until its circumference touches the inside of the Bell; it is then drawn into its final position parallel to the axis of the Tube among the other five, so completing the construction of the ring.

To facilitate the introduction of the last segment among the others already in position, it is made taper, touching the others on either side only when in its final position. It is then firmly bolted to those of the preceding ring as well as to those it joins.

Suppose, now, the segment as shown on Table (*f*), in Fig. 1, were drawn into the space (*m*), and had been finally bolted down; that the table were withdrawn from it and were brought down to touch the boss (*c*), ready to take hold of another plate to commence the construction of the next ring; then the whole operation from the beginning of a day's work would be as follows:—A train of about 32 waggons, each conveying the load of one segment, would be started from shore, the loaded waggons being in front. The segments will be held by the waggons in a definite position and within a definite height from the level of the rails; each will rest on two waggons, at either end upon one, reaching from the middle of one waggon to that of the other, connecting the waggons together and bridging them over. They will be so loaded that every six of them will carry those of one ring; the very segments that were forming part of the ring during the turning operation. About 32 waggons will take 12 hours' supply; and within two hours the train may reach the 21st mile of the Tube in course of construction.

At the end of the Tube, for a distance of about 120 yards, there will be a line of temporary rails (*n, n*) attached to each side of the Tube, as shown in Fig. 2. They will be of V shaped section

supported by temporary brackets, attached to the flanges of the rings. While the segments are upon the waggons, they will be about 1 inch above the level of these rails, so that the loaded waggons may pass clear over these rails up to the frame (*C*), close to within the very last rings within the Bell. The train having arrived at its destination, the segments will be lowered by screw motion, until they come to rest upon the temporary rails (*n, n*). This position of the segments is shown in Figure 2, which represents a section through one of the completed rings of the Tube within the Bell, looking from the Tube into the Bell.

The train back to shore will consist of empty waggons. Some tank-waggons will be left behind close to the frame (*C*) to receive the waste water from the hydraulic presses. The Tube at its end is now supplied with segments for about 12 hours' work, all of which are deposited upon the temporary rails (*n, n*), which lead to the very last completed ring of the Tube. In our section Fig. 1, two plates (*a*) are shown as deposited by the train. One of these plates will then be hauled forward by a small water engine from the press chamber of the Bell to the position of the segment (*b*), shown in dotted outline, that is,—right into the last completed ring of the Tube. The sliding turntable may now be moved under this segment, by a piston working in the cylinder of the frame (*C*), using hydraulic power. Water from the accumulators being now gently admitted into the two cylinders (*d*) of the turn-table, its table (*f*) will rise between the flanges of the segment (*b*) until it touches its inner surface. The water is now shut off, and by means of four little hand wheels (*o*), four conical bolts (*p*) are made to enter right into four bolt-holes already drilled into the flanges of the plate, required in the construction of the rings. Thus, the segment may firmly be tied to the table in a few minutes. This operation completed, water may now be admitted into the horizontal press within the frame (*C*), and the turntable, with the segment attached to it, may now be pushed forward along the main shaft (*B*), until the full stroke of the piston is completed, when it will be in a position within the fitting chamber of the Bell freely to place, and finally to deposit, the segment as part of a new ring to be constructed.

The segment is still upon the table close to the boss (*c*). By admitting water into a pair of engines, working the crank (*l*), the table may now be turned into any required position round the main shaft (*B*). The desired position being obtained, water may now be admitted into the two cylinders (*d*), and the table with the segment will now be pushed from the main shaft or the centre of the Bell towards its circumference, until the annular ring of the plate will touch the inner surface of the Bell.

Water being again admitted into the horizontal cylinder within

the frame, the segment will now be drawn close to the flange of the last completed ring, a circular projection (*r*) of it fitting exactly into a corresponding circular groove (*s*) on the flange of the ring. Thus the position of the plates will be fixed with great precision, locking them together. The segment may now be bolted to the last ring, and the table may be released from it by turning the small hand wheels (*o*) in the reverse direction. The two pistons (*e*) may now be drawn into their respective cylinders by changing the direction of the water pressure, and the table (*f*) will now be brought down right upon the boss (*c*), ready to be slipped under another segment, which in the meantime had been hauled to the place from which the first was taken away by the table, and the whole operation above described may now be repeated with segment No. 2, and so on, until the ring is constructed.

It will thus be seen, that from the time the segments are started from shore to their final destination and position within the Tube, they will not be touched by the hands of any workman. They are carried into the Tube upon an ordinary train; on their arrival, they will be deposited upon temporary rails by screw motion; from these, one by one, they will be hauled forward by a small water-engine to within the last completed ring; here they are in succession picked up by the sliding turn-table, placed and held in position within the circumference of the Bell whenever required, until they are finally bolted to the completed end of the Tube. The workmen have only to open and close certain valves, distributing the water from the accumulators to the various hydraulic engines; they have to insert the bolts, to add another length of rails, and another pair of brackets for the support of the segments as the Tube lengthens, taking down a corresponding length at the other end; as soon as the bolts are inserted, they have to caulk the joints; they have to add another length of pipes for the supply of air and water, for bringing the pure air to the very end of the Tube, forcing the tainted air out at its shore end, and for supplying power from the accumulators to the various machines; for all these operations workmen will be required. The Tube could not be built without a number of good workmen, and without proper superintendence; but these are principally wanted to direct the power and the use of the various machines, and not for their individual strength.

It may be perceived that, assuming the arrangements to be good and satisfactory, the progress in the construction of the Tube should be rapid, and will mainly depend on the speed with which other operations may keep pace with the progress of building within the Bell.

It may be observed that each segment, before it is sent into

the Tube for its final destination, is not only complete as far as the mechanical operations of planing, turning, &c., are concerned—as far as it forms part of the ring—but it is also provided with the water-tight joint within the groove upon its annular disc.

This joint would be similar to that used for ordinary hydraulic presses. A water pressure of about 200 feet would be the maximum; it is but a small portion of the pressure which similar joints in hydraulic presses have to resist in keeping them water-tight. Each segment will, moreover, have attached to it corresponding parts of a lead ring, for caulking the circular and longitudinal flanges, so that the operation of caulking from inside the Tube may be commenced as soon as a ring will be completed within the fitting chamber of the Bell.

At suitable distances, principally depending upon the nature of the ground, the head of a screw-pile will, be attached to a segment, as shown at the ring (*E*) in course of construction. So soon as the Bell in its progression has passed over the ring (*E*), the screw-pile will be sunk into the ground by suitable machinery, the shaft having previously been attached to the screw. On an average a pile will be introduced at every third ring; and at every sixth, two piles, one at each side, 30° inclined towards the vertical line, to tie the Tube also in the lateral direction, as shown in Fig. 3 by dotted lines; the section representing the Tube when finished.

The distance between pile and pile along the proposed line will, as already mentioned, in some measure depend upon the nature of the ground. The piles need not be closer together, unless the ground were very uneven and loose; they should not be much farther apart, unless the ground were not suitable for rapidly driving them. For the proposed average section of the Tube the distance between pile and pile should not be greater, in order to keep the leverage of the Bell on the Tube within definite limits; but, with increased diameter of bolts, the distance might be considerably increased. Although the weight of the projecting part of the Tube and Bell will be little or nothing—displacement being made equal to their weight—and there will be on that account no strain on the Tube, yet, for obvious reasons, it is not desirable to keep the Bell too far ahead from the last pile or piles on the line already built.

In crossing sudden and short depressions of the channel, every ring will have one pile or more, the direction of the Tube being maintained without regard to local depression. The depth to which the piles will have to be screwed into the ground, will entirely depend on the nature of the bottom of the channel. A pile should be sunk until it obtained a firm footing; and whether a pile will have to be screwed 10 or 50 feet cannot be determined

beforehand. It is the operation of sinking the piles which will mainly control the daily progress of building the Tube within the Bell, for both these operations must keep pace with one another.

On the average, however, four piles should be conveniently driven into clay, gravel or sand, in 24 hours by the aid of suitable machinery, for which the power on hand is practically unlimited; for all the mechanical operations will receive their power from accumulators on shore.

Once fairly under water, 10 rings may daily lengthen the Tube. The progress may, on the average, be 100 feet per day, or one mile in two months. With the exception of the two shore ends of the Tube, the Channel may be crossed in $3\frac{1}{2}$ years.

With a bottom of sand, gravel or clay, the Bell may be kept ploughing the ground on the average about 3 feet deep, shaving off any unevennesses in the bed of the Channel. There is ample power on hand for this operation. The hydraulic power in the press chamber of the Bell will give above 2,500 tons margin for lateral resistance of this kind—which, if need be, might be doubled without difficulty—a pressure which would not only be sufficient to scrape a couple of feet off a sandy bottom, but it would readily shave off rocks of the chalk formation. If rock were, however, met with on the bottom of the Channel, it is not intended to disturb the rock, but to pass the Bell over it.

The nature of the ground to be passed over immediately in front of the Bell will be accurately known. A detailed survey will be kept up several hundred yards in front of the Bell by special surveying vessels; so that not only the character of the ground to be passed over, but every slight elevation or depression will be known, and provision may accordingly be made for the required distance of piling and the best form of pile for the kind of ground.

Provision will also be made for elevating or depressing the Tube to suit the inclination of the ground, provided such elevation or depression were to continue for some distance, otherwise it would be passed over by maintaining the original direction, merely adjusting the piling to the irregularity of the ground.

The ultimate resistance of the projecting part of the Tube, with a leverage of 100 feet from the last pile, against lateral or vertical pressure, is at that point about 400 tons; this refers to the average section, which, if required, might be further greatly strengthened. The weight of the projecting part of the Tube and the Bell, and all the machinery within it, from the last pile which had been tied into the ground, is practically zero, because displacement and weight are made to nearly balance one another; and for the purpose of correct adjustment a buoy or air chamber will be permanently fixed to the top of the Bell, as

shown in outline upon the sections, Figs. 1 and 2. Should, however, a pressure of 400 tons or more be brought upon the Tube, or rather upon the foremost part of the Bell, supposed to be 100 feet ahead of the last pile, the consequences may be easily seen—the last pile, or couple of piles, will give way long before such a pressure could be reached, and the piles would either be pushed deeper into the ground or would be raised out of it, until the Tube and Bell, or either of them, were resting on the bottom; the piles will be made to give way first, either by depression or elevation, and thus to indicate undue lateral or vertical pressure in front of the Bell, from whatever cause. With this view they will not be tied into their permanent position as soon as the Bell will admit sinking them, but only to such depth as may be deemed sufficient to meet all ordinary resistance and pressure which might reasonably be expected.

The gradients on the proposed line of the channel are gentle, and the Tube might be left to adjust itself to such gentle elevations or depressions. Occasions may, however, arise, when a deviation from a straight line, in which the Tube would always keep the Bell, might be desirable or even imperative. We must be able to build the Tube also upon a curved line, either in a lateral or in a vertical direction, to avoid, for example, a formidable obstruction, which the detailed survey of the bottom of the Channel may bring to light. This may readily be accomplished by making the discs on which the Bell slides moveable on the body of the Tube, instead of letting the tubular ribs on the segments guide the Bell. In every 40 feet a rise, or fall, or lateral deviation, of about 4 inches may be given, corresponding to a radius of a little under 5,000 feet, or under one mile. Within the length of one mile, therefore, the Tube might be turned round at right angles with its former direction. A rise or fall of about 36 feet may thus be given to the Tube within 200 yards, either to pass over an obstruction on the line or to follow a rise or fall in the bed of the Channel; and within 500 yards it might be made to rise above high water line from the deepest part of the Channel.

But not only may the tube be built on a straight line or upon a curve, closely following the bed of the Channel, turning right or left, but it may also be picked up by reversing the operations within the Bell. This may be accomplished by taking advantage of the pressure of the water upon the end of the Bell, which, when relieved from pressure behind, will be forced back upon the Tube. The pressure upon the end of the Bell will vary, according to the depth of the water, from 700 to 1,500 tons. If the Tube had, for instance, been built in a direction which would bring it too suddenly upon an obstruction, and which a curve of one mile radius would not clear, then by

taking down the segments already fixed, and by sending them on shore as ring after ring were removed, and by unscrewing the piles as the mouth of the Bell would approach them in its retreat upon the Tube, so any part might be taken down again and a new start may be made in another direction.

About 200 yards from the Bell the operation of finishing the Tube may be carried on. The space between the flanges of each segment will be filled up with a lining of brick in cement and over the brick lining about $1\frac{1}{2}$ -inch cement will be laid, in which the wrought iron skin or inner facing of the Tube may be bedded. The skin will at its margin be rivetted to the longitudinal flanges of the segments by small screws tapped into the flanges, countersunk on the surface of the wrought-iron plates. Over each segment there will be one plate $\frac{3}{8}$ -inch thick, forming the skin; and when finished, the Tube will be a continuous cylinder of smooth surface, like the inside of an ordinary pipe. At the junction of the segments, however, the caulked lead joint will always remain exposed to view. If a drop of water were to leak into the Tube at any of its joints, it could be seen, and the leaky place might again be caulked until that very drop were excluded. The Tube in its whole length may not only be kept watertight, but it may be kept quite dry; the exposed lead joint will insure tightness and dryness within the Tube from shore to shore.

Fig. 3 represents a transverse section of the Tube when finished. A passenger carriage of the latest construction is also shown. The carriage is of ordinary size as at present in use on the South-Eastern Railway. It will conveniently pass through the Tube.

No. 3.

Starting the Tube on Shore.

To start the Tube on shore will be a more formidable operation than to build it in deep water across the Channel. The Tube will be commenced above high water line, and the operations will be as follows:—First, the finished rings of the Bell will be put together in the ordinary way on shore, upon the proposed line of the Tube above high water; the axis of the Bell coinciding with the direction adopted for that of the Tube. For this purpose a special foundation of concrete and masonry will be made for the Bell, to hold it firmly and in the right direction. On this foundation the Bell will temporarily be bolted down. The whole machinery for building the Tube in deep water will then be erected and fitted within the Bell. Three rings having also been put together in the ordinary way within the Bell—the construction of the Tube may now be started with the aid of the machinery,

the various operations being in every respect similar to those described for building the Tube in deep water. In starting the construction of the Tube on shore, the Bell is to be the fixture from which the first 100 yards of the Tube will issue. This start having been made, the Tube will in turn become the fixture and the Bell the travelling part. Accordingly, the Bell being firmly held on its foundation, the hydraulic presses will push out the Tube from the Bell, as ring after ring is being built within its fitting chamber. The ground in rear of the Bell will be prepared for about 100 yards length, and a foundation of concrete will be laid for the Tube which, as it issues from the Bell, will slide over its future foundation on slips, similar to launching vessels, except that the Tube will have to slide up an incline of about 1 in 100.

Having in this way constructed about 30 rings within the Bell, which will have produced about 100 yards length of Tube, it will be surrounded with concrete and masonry, embedding the first 100 yards of its length into its foundation.

The Bell will now be unbolted from its own foundation, the level of which will be about 4 feet below the surrounding ground, but above high-water line. A trench will now be made on the proposed line of the Tube in front of the Bell—gradually reaching to low-water line—the trench being about 5 feet deep and 30 feet wide. On the bottom of this trench, a timber slip will be laid, upon which the Bell will slide in its progression to the sea.

Having by degrees reached low-water line, the trench and slip will be discontinued, and the Bell will now cut its own trench, and will bed itself in the ground by its progression, which will now be limited to high-water, until it had reached such a distance into the sea that it will be covered also at low-water line. The operations of constructing the Tube under water will then fairly begin, and from that time they may be continued without intermission.

The shore end of the Tube will be of greater thickness of metal, and each ring of this section of the Tube will have two piles. For starting and also for landing the Tube on the opposite shore we have choice of ground, and we may therefore select the best foundation for these operations. A foundation of coarse sand or clay will be suitable for the purpose.

Another mode of proceeding might be adopted, by keeping the Bell suspended upon the rings of the Tube, which project into it from the last piles, and so to carry the Bell on the Tube by degrees into deep water. This mode of proceeding might be adopted, and would be suitable for starting the Tube upon a foundation of chalk, but it would be more expensive and less expeditious than guiding the Bell upon slips into deep water.

Having crossed the Channel, and the Bell having reached low-water line on the opposite shore, the operations will now be

confined to high-water until the Bell will reach high-water line. A slip will then be laid in front of the Bell during low-water, similar to the slip used for guiding the Bell into the water, but now for guiding it out of it on the dry land,—which being accomplished, the Tube will be finished from shore to shore.

No. 4.

Details of Construction.

It may be desirable to explain some of the details of the mechanical arrangements in building the Tube within the Bell, and also to refer to the effects which an alteration of certain dimensions and quantities of the construction may produce. Let us again consider the 20th mile completed, and the 21st in course of construction.

All the power within the Bell is derived from accumulators on shore. The power must be conducted to the very end of the Tube. Equally important is the supply of fresh air during the progress of the works. Special pipes will convey both water and air from shore into the Bell. These pipes are shown in elevation and section, Figs. 1 and 2. A pipe (*G*) of elliptical section will supply the air; it is elliptical because the greatest area was sought for which circumstances would permit, the height of the pipe being limited by the axle-trees of the waggons, which have to pass over it; the width of the pipe is limited by the gauge of the rails. The air-pipe has a sectional area of about $3\frac{1}{2}$ square feet. Under a pressure of about 20 inches mercury on shore, it will deliver at the twenty-first mile 100 cubic feet of pure air per second, which will fill the Tube at a rate of half-a-mile an hour at its very end within the Bell, displacing a corresponding quantity of tainted air at its mouth on shore. Each air-pipe will be about 10 feet long, the same length as the rings of the Tube; and with the completion of a ring in the Bell, another air-pipe will be attached to the main line, keeping pace with the progress of the Tube.

Along the line of air-pipe there will be two lines of small pipes (*i*) for the supply of water from the accumulators on shore. These pipes will be of steel, 2 inches clear diameter, $\frac{1}{2}$ -inch thick and also 10 feet long; they will be drawn-steel tubing, and will be supported upon the flanges of the line of air-pipe, as shown in Figs. 1 and 2. One of these pipes will supply water exclusively for the use of the main hydraulic presses of the Bell, under a pressure of about $1\frac{1}{2}$ ton per square inch. The other pipe will supply water to the various machines under a pressure of about half-a-ton per square inch. These pipes are similar, because it is intended to use them

alternately for either pressure, in case of repair upon either of the line of pipes. The last length of these pipes discharges its water into another larger pipe, which at the same time is a piston of a cylinder in the frame (*C*). This piston is 5 inches diameter, and its object will presently be explained. Each line of pipes has a similar arrangement. The water from the accumulators on shore will accordingly be discharged into these cylinders (*F*), which form part of the frame (*C*). From these cylinders the water may be distributed by valves and small piping to the presses and the various machinery. Of these distributing pipes four are running along the main shaft (*B*), within grooves upon its sides. Two of these are supply-pipes of high and low-pressure water, and two are discharge-pipes conveying the waste water to the valves, whence it is discharged into tanks upon waggons by india-rubber tubing. Two small distributing-pipes and corresponding valves are for working the cylinders (*d*), upon the turntable, and another pair of similar pipes for working the horizontal piston within the frame (*C*), for sliding the table to and fro.

The two pistons into which both lines of water-pipes discharge their water from the accumulators, and which work within the cylinder (*F*), are with a view—first, to allow the construction of another ring of the Tube without the addition of another pipe; the piston sliding within the cylinder and adjusting itself to the increased length; second, to push the frame (*C*) constantly ahead against a shoulder on the main shaft (*B*). The frame (*C*) will thus move simultaneously with the Bell, with a lateral pressure of about 40 tons, but the power of the main presses within the Bell can never be exerted upon the frame.

We shall now briefly consider various effects, which an alteration of some of the dimensions will produce. An increase of one inch thickness of metal to the cast-iron shell of the Tube, making it thereby nowhere under five inches thickness, will increase the weight of the cast-iron construction by 20 per cent. A thickness of four inches of the shell of the Tube will be ample; but it may be readily seen that if it were deemed advisable to increase that thickness, it would not in any way affect either the proposed mode of building the Tube, or the proposed machinery. The strength of the Tube as proposed is, for all practical purposes, ample, and an increase of the thickness of its shell could only be proposed with a view to counteract the effect of the sea-water upon cast-iron, which by degrees tends to reduce its thickness by corrosion. But the possible effect of sea-water upon the cast-iron shell of the Tube is so remote that it cannot have much weight with us. Fifty-two years of submersion of the cast-iron guns of the Royal George in the tidal waters of the Channel have practically produced no impression upon them. The effect of

the sea has been but slight, it does not exceed anywhere an eighth of an inch, if it should amount to that much. A fine specimen of an old 38-pounder of the Royal George may be seen at the Tower, with the inscription, "Recovered from the wreck of the Royal George of 100 guns, in the year 1834." The Royal George was sunk on the 29th August, 1782, and, we are informed, these guns "having lain under water 52 years were recovered by the ingenious diving apparatus of Charles Anthony Deane, in the year 1834." There are various specimens, some of cast iron, others of brass, large and small. The whole Tube, as exposed to the action of the sea, will have its original cast surface unimpaired, not any part of which will be subject to mechanical operations; accordingly, we may take it, that half a century will produce but a small effect upon the Tube, and it is probable that the effect of a century would be of no account. To increase the thickness of the Tube to meet the effect of corrosion at so remote a period would therefore be neither necessary nor desirable, for the expense of an additional inch capitalised would at that time amount to a sum large enough to build several new Tubes.

The diameter of the tube was determined with a view to give ample room for the passage of ordinary carriages and waggons, so as to let them pass the Tube without a break in their journey. An increased diameter would hardly offer a material advantage as to convenience, whilst without correspondingly increasing the thickness of metal it would reduce the strength of the Tube against compression. Within limits a larger Tube may be built with more convenience than a smaller one, though with increased cost. We believe the proposed diameter of the Tube will meet the requirements of the case.

The dimensions of the Bell are in a great measure determined by those of the tube; its inner diameter determines the extreme outside of the Tube, viz., the diameter of its tubular ribs. The length of the bell depends almost wholly upon the length adopted for each course of ring, reducing which would in proportion reduce the length of the Bell; for example—a Bell of only about half the length of that proposed would be required for the same Tube, if its rings were only five instead of 10 feet long; but it is obvious that by reducing the length of each ring the number of joints along the line would be increased, and the daily progress in building the Tube would be smaller. A thickness of eight inches is probably too great for the Bell, but inasmuch as repairs upon the Bell would be difficult, or even impracticable in deep water, a thickness was determined upon which will put the Bell beyond the possibility of injury from any cause whatever by accident or otherwise. In the deepest part of the Channel the resistance against a forward motion of the Bell will be about 1,500 tons; the united

power of the four hydraulic presses for the purpose of moving the Bell is, at the assumed water pressure, equal to about 4,000 tons, leaving a balance of about 2,500 tons for other resistances.

The contraction and expansion of an iron Tube of so great a length also require consideration. On the bottom of the Channel the change of temperature is but small, and the effect produced on the Tube by a small change of temperature cannot be much. For every 10 degrees Fahrenheit change in the temperature of the sea, the total expansion or contraction of the Tube would be about 7 feet. Probably such an expansion upon such a great length, would adjust itself in the elasticity of the material. But an expansion joint might be introduced at every mile, which would allow for expansion or contraction.

The effect of currents upon the Tube is also but slight. The superficial velocity of spring tides in the Channel is under 3 knots an hour; the velocity of the current at the bottom of the Channel must be considerably less; but, assuming it to be the same, such a current would produce a lateral pressure of about half a ton per yard length of the Tube, with a tendency to carry it with the current. That such a pressure could have no effect upon the Tube, even if it were not tied to the ground by screw piles, is obvious enough.

The body of the Tube will be about 14 feet above the present bed of the Channel, it will therefore somewhat reduce the water-way, and it might on that account be considered an obstruction. Except for half a mile at either end the largest ships might pass for 20 miles across the Channel, with from 40 to 150 feet of water between their keel and the top of the Tube. The water-way would be somewhat reduced, but there are close by sections of the Channel in which it is considerably less. We are seeking for the Tube the deepest and most uniform part of the Channel. Though the water-way would be a little less, it could have no injurious effect either upon the currents or upon the navigation of the Channel. At either shore end an open pier and lighthouse, or other protection for the shipping, will be built along the Tube, to indicate its line; such protection would be continued to a distance into the sea, until at low water there would be about 30 feet of sailing depth.

If by accident a man-of-war or other large ship were to sink right upon the Tube, the effect produced may readily be seen. The Tube is nowhere less than 4 inches thick; circular, about 14 feet diameter, strengthened by tubular ribs all round, also 4 inches thick. On the other hand, the bottom of a man-of-war, or other ship, may be perhaps $1\frac{1}{2}$ inches thick, flat, with about 1 inch ribs. It is evident the Tube will crush in the bottom of the ship and will bury itself in it, the vessel being by far the weaker of the two.

As to grappling the Tube by anchors—it is difficult to see how

an anchor could take hold of it, the exterior surface of the Tube being everywhere cylindrical without any recesses; but assuming such a thing possible, it would be very much in the style of grappling a whale with a salmon fly—for the heaviest anchors and chains in use on board any ship, in comparison to the dimensions, the metal, and the strength of the Tube are mere hooks and threads. A thousand tons lateral or vertical pressure or tension anywhere along the line of the tube, will produce not the least effect upon it. Let us bear in mind the Tube is a gigantic structure, worthy, we hope, of the gigantic results which its completion would insure to the nations of Europe.

SECOND SECTION.

No. 5.

Mode of Working the Traffic through the Channel Tube.

In this Section we shall have to consider an important and difficult problem. The question is, how are we to work the traffic over the Channel Railway, a junction, which is connecting the main lines of England and France, and which at the same time is to be within a Tunnel of some 22 miles length?

If this junction line were an ordinary one in every respect, except that we were confined to one line, or perhaps two lines of rails,—it would be perplexing enough to pass over it the tonnage of several main lines, and to do justice to the requirements of the traffic. But the problem is encumbered with another condition, viz, this line is to be within a Tunnel 22 miles long.

This condition involves the difficulty of ventilation. The Tunnel could not be worked at all, unless the air within it were fit for human beings; it might be impure, but it must not be injurious. The quality of the air within the Tunnel becomes, therefore, the paramount question; and the tonnage that might be passed through it, a secondary one.

What does ventilating a Tunnel mean? It means—removing the tainted air and replacing it by fresh air; both these operations require motion of air. The question therefore resolves itself into

an investigation of the motion of air within a very long Tunnel or a very long Tube ; for, so far as the motion of air is concerned, there is no difference between the two.

The degree of the change or of the motion required, will in a great measure depend upon the extent of the traffic. But we cannot deal with indefinite quantities, we must, therefore, assume an amount of traffic which will pay at moderate rates upon the capital to be expended in the construction of the line, otherwise the whole proposition must ever remain a failure.

From another part of this work it will appear, that, considering all the circumstances of the case, the capacity of the line should not be under 10,000 tons displacement of goods in 24 hours. It does not follow that 10,000 tons of goods must be daily displaced to make the line pay, but that, considering all the circumstances, the capacity of the line should be equal to so much to warrant the execution of this exceptional work. Assuming first-class engines and waggons of ordinary construction, about 50 trains would be required to displace daily that amount of tonnage, if worked by locomotive power in the ordinary way ; accordingly, about 1 train would have to pass through the Tube every half hour. The average time of passage for each train would be about one hour, and as the engine during the journey would at least consume half a ton of fuel, so at least one ton of fuel would be burnt within the Tube per hour.

We have it on high authority that " $\frac{1}{10}$ ths per cent. of carbonic acid in air is a very objectionable quantity, although it is frequently exceeded in mines ; that carbonic oxide is far more poisonous, and that $\frac{1}{1000}$ th per cent. of this gas in air would probably be a dangerous quantity." In the most perfect combustion the carbon of coal or coke should all be burnt into carbonic acid ; but in practice no furnace will produce such a result. The gases from the combustion of carbon will, in ordinary furnaces, always contain a mixture of carbonic acid and carbonic oxide, the quantity of the latter gas depending in a great measure upon a more or less perfect combustion.

Accordingly, with the most perfect combustion, if the whole carbon were converted into carbonic acid, for every ton of coke burnt within the Tube about 3 tons of carbonic acid would be produced, to neutralise which, about 500 tons of fresh air must be introduced to make the air tolerable within the Tube. With ordinary combustion, however, the carbonic oxide must be also considered, and though only a small part of the coke burnt might be converted into this gas, yet, as one part in thirty thousand of air would be a dangerous quantity, we should have to introduce still more fresh air per hour, sufficiently to dilute it and render it tolerable, although not safe.

But assuming the most perfect combustion to be insured, we should still have to remove per hour more than 500 tons of tainted air from the Tube, and should have to introduce an equal quantity of fresh air, to neutralize the injurious effect of carbonic acid resulting from combustion. The size of the Tube does not affect this part of the question; if it were a larger one it would allow the passage of a greater number of trains before the air within it would be tainted to that degree; but having once reached that degree, which would soon be the case, then more than 500 tons of fresh air must be introduced to counteract the effect of further combustion.

To send 500 tons of fresh air per hour into the Tube of the proposed section, a current of a velocity of about 20 miles an hour would be required. To maintain within the Tube such a current, a difference of pressure in the atmospheric condition at its two ends of about $3\frac{1}{2}$ inches mercury must be produced, or about $\frac{1}{10}$ th of an atmosphere. No system of shafts could possibly create such a difference of pressure. A shaft two hundred feet high, in which the air had been heated to 500° Fahrenheit, would not produce a greater difference of pressure than about $\frac{1}{300}$ th part of an atmosphere, or a column of mercury of about $\frac{1}{10}$ inch., whilst the column required to produce the current is $3\frac{1}{2}$ inches.

Nor would a number of shafts be of more service; for whether there be one or several at either end, the difference of pressure which any of them could create would still be the same—they would partly balance and partly disturb one another; but in reference to the whole length of the Tube they would be drawing jointly with a difference of pressure of $\frac{1}{10}$ inch mercury, and they would receive and raise whatever the Tube might supply them under such a difference of pressure. To produce the current within the whole length of the Tube, pressure is wanted, and a number of shafts can give no increased pressure over that produced by one. At the required velocity of current the pressure of about $3\frac{1}{2}$ inches is wanted to overcome the friction of the air against the surface of the Tube.

This is so serious a point that it opens the question whether a Tube or Tunnel between England and France could be of any use after completion, if it could only be worked by locomotive power; for, if the number of trains were limited to half a dozen a day or so, the completion of such works would be of no effect, and consequently of no practical value.

A larger Tube would require smaller pressures because of the reduced velocity; but the power of ventilation which a system of shafts might offer is so utterly inadequate and disproportionate, that the idea of gaining the point by some such means must at once be abandoned.

How are ordinary Tunnels ventilated? They ventilate themselves. In Tunnels of ordinary length the speed of the trains will create currents, which by degrees will change the air within; and by the assistance of shafts the tainted air may be made tolerable for a short time. But all these accessories of ventilation become infinitesimal within a Tube or Tunnel of 22 miles length, whilst the resistance offered to ventilation is for every additional mile proportionally increased. The effect of a certain quality of tainted air upon passengers is also increasing with every additional mile, because of the increased length of time during which they are exposed to its injurious effects.

The difficulties appear to increase with a longer Tube or Tunnel in a compound or rapid ratio. In the present instance, we believe, they could not be overcome in the ordinary way.

To produce proper ventilation, or what is the same thing, to maintain a current within the Tube of a definite velocity, we must rely upon mechanical means and power. Taking again for example a current of 20 miles an hour, we must, by some mechanical means, displace about 4,000 cubic feet of air per second; and assuming the air to be forced into the Tube by blast-engines, we would require 700 square feet area of pistons, with a mean velocity of 6 feet per second; and inasmuch as even a cylinder of a sectional area of 50 square feet would be a formidable affair, we should require about 14 such engines merely to maintain a current within the Tube, and an indicated power of about 2,000 horses. Centrifugal fans and the like would be found utterly wanting because of the degree of pressure under which the air must be supplied.

Although by such means the object might be gained, it would undoubtedly be a costly and complicated plan. A reserve establishment would also be required, and the item of maintenance in so great a number of blast-engines would be a serious matter.

This difficulty might, however, be met by the use of cylinders of different construction. We propose, for example, cylinders 100 feet diameter and 50 feet stroke, but not cylinders like those of blast-engines—of cast-iron and bored out—but like those of ordinary gasometers,—a shell of wrought-iron plates, rivetted together, within which water is to perform the office of a piston, the cylinder to perform the stroke, and so to displace the required quantity of air. By these means a practically unlimited area of piston may be obtained at a small cost and with very little maintenance. In this manner we may, without difficulty, displace a very large volume of air with certainty, convenience, and with economy of power, and under a pressure of many inches of mercury.

Still, with all these means, the Tube is only ventilated to a degree which will make it possible to exist in it; the air would, in a great measure, still be tainted. The working of the Tube

may, by these means, have been rendered practicable and tolerable, but not agreeable.

We have now, we assume, powerful air pumps and machinery on shore, which will readily displace, under a pressure of many inches of mercury, as large a volume of air as we please. An additional inch of pressure applied upon a piston of the area of the Tube would give a lateral traction power of 5 tons, or as much as a heavy engine is able to produce. It is but one step to make use of all this power and machinery also for the propulsion of the train, doing away altogether with the danger and nuisance which the combustion of fuel will inevitably create in so long a Tunnel, and then Pneumatic pressure becomes the means for displacing a high amount of tonnage between the main lines of England and France, doing away at once with all the serious difficulties which surround the working of the traffic.

Should there be any doubt lingering in the mind of the reader as to working the traffic by Pneumatic pressure with certainty, or as to the plan being reliable at all times, provided it can be applied in a proper manner, let us only observe, that no one doubts the power of steam in our days, because we have examples innumerable of its elastic force. Now, the elastic force of air is much more reliable than that of steam, simply because cooling alone annihilates the power of the latter without producing mechanical effect, whilst with the former, change of temperature but slightly affects its elastic force, and as surely as a piston of a locomotive engine is propelled by the elastic force of steam, so will a piston fitting the Tube be propelled by the elastic force of the air; and more certainly so, for the reason already mentioned.

The construction of the proposed Tube is particularly favorable for the use of Pneumatic pressure; it is truly cylindrical, all its parts having passed the lathe, and, although it is not bored out from end to end, it will be seen that this would be wholly unnecessary. The slight pressure required over the large area of the Tube to produce the desired traction, will admit a free space all round between the circumference of the piston or disc and that of the Tube; it may be about half an inch without any serious leakage, in fact, if the Tube were bored out from end to end, it would not be practicable to make the disc fit tight within it, because, at the proposed velocity of the train, it would soon heat, and an inordinate amount of friction would be produced. What is wanted is, that the free space all round the disc should bear a small proportion to the sectional area of the Tube, and that it should be uniform throughout. By these means, we have within the Tube a disc moving without any friction whatever, and without any wear and tear; and by using in each train several such discs, dividing the train into sections, the leakage of air round them will

be reduced to a mere nominal figure. It is rather desirable there should be some air passing along the train, to create a moderate current, otherwise the air would be stationary in reference to the train, both travelling together at the same speed.

But the Pneumatic system will not only insure purity of air within the Tube—the pure sea air accompanying every train without exception,—but it will insure also a degree of safety in transmission, that by no other means could even be approached. Serious accidents from collision, arising from mistakes in the construction of the train, or from misunderstanding of signals at either shore-end, and the like, could not possibly occur. In the ordinary way of working railways the sources for such errors and mistakes are almost innumerable, to say nothing of negligence, which can only be reduced and modified by perfect supervision and great discipline. With the Pneumatic system of working, serious accidents are, in fact, out of the question; for the result of all such errors, mistakes, and even of negligence, could only produce one thing, viz., delay in the transmission of the train.

We propose, therefore, to work the traffic through the Tube on the Pneumatic system of propulsion. We believe its operation will not only be found satisfactory, but that it will insure a degree of safety, and will place an amount of power and control over the movements of the train in the hands of the engineers, that no other means which we are acquainted with could place at their disposition.

No. 6.

Working the Traffic by Pneumatic Pressure.

On the Pneumatic plan of working, the elastic force of the air will propel the train through the Tube. Its elastic force may be made effective, and may be displayed in two ways:—1st. By reducing its tension or pressure at one end, leaving it undisturbed at the other. 2nd. By increasing its elastic force through compression at one end over that at the other. In either case a difference of pressure is created. Assuming, for example, the air to be at a tension measured by a barometer of 30 inches mercury; suppose we reduce by expansion its tension to a degree, that a barometer within it would only read 26 inches; then a difference of pressure will have been produced, measured by a column of 4 inches of mercury. Having created a difference of pressure at the two ends of the Tube, the air will flow from one end to the other with a velocity, which will depend on the difference of pressure, and upon the amount of resistance which the air may meet with in its motion through the Tube.

For the sake of simplicity we shall first consider the motion of the air as a result of a difference of pressure, omitting altogether the train. We shall ascertain the various degrees of pressure required to make the air move within the Tube with certain mean velocities per hour; bearing in mind that the resistances to be overcome by these pressures are due to the friction of the air upon the surface of the Tube.

There are various formulæ by which the pressures for different velocities of the current may be calculated; they agree closely in their results. We find, that within a Tube of the proposed Section and length, and under ordinary atmospheric conditions, a current of a velocity of 10 miles an hour will require a difference of pressure of 0·825 inch mercury. This result has been checked in various ways, and will be found to be very near the truth.

Accordingly, in order to make the air pass through the Tube with a mean velocity of 10 miles an hour, and the barometer being at one end of the Tube at, say, 30 inches, it must at the other end stand at 29·175 inches. This atmospheric condition being maintained at either end, a current of air at a rate of 10 miles an hour will also be maintained within the Tube.

To produce certain mean velocities of current, the pressures required will increase or decrease as the square of these velocities; to maintain, therefore, currents within the Tube at 1, 5, 10, 15, 20, 25 and 30 miles an hour, the corresponding pressures, if expressed in columns of mercury, would be:—0·008, 0·206, 0·825, 1·857, 3·302, 5·159, 7·428 inches; or to maintain, for example, a current at a rate of 30 miles an hour, the difference of pressure at the two ends of the Tube must be 7·428 inches, or nearly one-fourth of an atmosphere.

The effective power expressed in indicated horses, to be usefully exerted by the air-pumps while they are producing those pressures and maintaining those currents within the Tube at the assumed velocities, would be correspondingly one-fifth, 26; 210; 709; 1,681; 3,284; 5,674; so that to maintain a current at a rate of 30 miles an hour, the effective power exerted by the pumps would be 5,674 horses.

Having now given the conditions of pressure and power to maintain currents of definite mean velocities within the Tube, we may now also consider the additional pressure and power for the propulsion of a train travelling with those currents. But inasmuch as the additional pressure and power for the propulsion of a train will mainly depend upon its gross weight, we must first determine what the weight of the train is to be. To assume the same train for all the velocities, would not throw much light on the subject, because the tonnage displaced would be different with every velocity; and as the amount of tonnage which might con-

veniently be displaced on the Pneumatic system is the principal question, we shall assume, that at all velocities of the train, the same amount of tonnage per hour or per day should be displaced.

Assuming, accordingly, a displacement of 500 tons of goods per hour through the Tube, or 12,000 tons daily, and considering that on the average a waggon may conveniently load five tons of goods, and that its weight will on the average also be about five tons, then the gross weight to be displaced per hour would be 1,000 tons.

Under these conditions, the train will be the more heavy the smaller its velocity, because it will take longer to pass through the Tube; on the other hand, the greater its speed the quicker will it complete its journey, and the less heavy need it be. If, for example, its speed were such that it would complete its journey in one hour, then the train would have to convey 500 tons of goods; but if it required twice as much time on account of only half its velocity, it would have to be twice as heavy to displace per unit of time the same tonnage, and so on.

For the convenience of consideration the same velocities will be assumed, for which the various pressures and the power have already been calculated, to enable us clearly to see the way in which the various quantities are increasing or decreasing, or even becoming impracticable.

We have, accordingly, calculated the effective horse-power to overcome the friction of the air and also the resistance of the train; the effective pressures, expressed in inches of a column of mercury; to overcome, 1st, the friction of the air; 2nd, the mechanical resistance of the train; the load of goods in tons; the number of waggons forming the train; the time of passage, and the lateral traction power required for each train at the various velocities—all of which, under the principal condition, that at the various velocities of the train the same result should be produced as to the amount of traffic displaced through the Tube between England and France.

TABLE No. 1.—*Showing Summary of result of Working the Traffic of the proposed Channel Railway Tube on the Pneumatic System of propulsion. 500 tons of Goods displaced through the Tube per hour, or 12,000 tons per day.*

Diameter of Tube, clear inside, 4 metres...13' 1½".
Length of Tube, from shore to shore, 22 miles.

Speed of the Train in miles per hour.	HORSE POWER.			PRESSURE.			Goods upon the Train in tons.	Number of Waggonss forming the Train.	Time required for the Train to pass through the Tube.	Required traction power for moving the Train.
	Indicated Horse Power to be exerted through the pumps on shore.	Column of mercury in inches at freezing temperature and at 30 inches barometer of the atmosphere.								
Miles.	Trac- tion.	Fric- tion.	Total.	Trac- tion.	Fric- tion.	Total.	Tons.	Num- ber.	Time.	Tons.
1	587	$\frac{1}{8}$	587 $\frac{1}{8}$	23·25	0·01	23·26	11,000	2,200	H. M. S.	98·2
5	587	26	613	4·65	0·21	4·86	2,200	440	4 24 0	19·6
10	587	210	797	2·33	0·33	3·16	1,100	220	2 12 0	9·8
15	587	709	1,296	1·55	1·36	3·41	733	143	1 23 0	6·5
20*	587	1,681	2,268	1·16	3·30	4·46	550	110	1 6 0	5·0
25	587	3,284	3,871	0·93	5·16	6·09	440	88	0 52 48	4·0
30**	587	5,674	6,261	0·78	7·43	8·21	370	73	0 44 0	3·2

* Ordinary Traffic.

** Express Traffic.

Much information may be derived from the preceding table. For the transmission of the same amount of tonnage the smallest velocity will require the smallest power; but every one of the conditions will become more and more impracticable as low velocities are further decreased; equally unmanageable will become the size of the trains. On the other hand: at high velocities the indicated horse power increases rapidly with a moderate increase in the velocity of the train. Glancing over the figures of the Table, it will be readily seen that the choice will have to fall between the 15 and 25 mile an hour velocity for the ordinary traffic. For reasons presently to be alluded to, the 20 mile an hour velocity has been adopted for the ordinary, and 30 mile an hour for the express traffic.

The gradients on the proposed line are gentle, and probably everywhere under 1 in 100. Yet in fixing upon a certain velocity and corresponding weight of train, it is desirable that the figure representing the column of friction should be higher than the column for propulsion, because in mounting an incline the train would, simply by slackening its speed, gain additional traction

power without the necessity of creating an increased difference of pressure by the pumps on shore. It is for this reason that the twenty mile an hour velocity was preferred to that of fifteen, the power available in the latter not being ample enough to make the train mount an incline 1 in 100 without additional pressure from the pumps being brought to bear on the train.

No. 7.

Exhausting the Tube.

As already stated, the elastic force of the air may be turned to account in two ways, viz., either by expansion or by compression. The operation of exhaust pumps consists in their creating by mechanical power additional space, into which the air may expand, the same quantity of air occupying thereby a larger volume and decreasing in tension.

In the following table we have calculated the additional space to be displaced by the pumps, and which, added to the original volume of the air within the Tube, will reduce its elastic force by definite quantities—viz., will reduce its tension inch by inch of the barometer. The normal condition of the atmosphere is assumed to be measured by a column of mercury 30 inches high, and it is proposed to reduce within the Tube the tension of the atmosphere from 30 inches to 29, 28, 27, &c. inches, and so on. The indicated horse-power to produce these various effects by the exhaust pumps has also been calculated, or rather the time during which a definite indicated horse-power on shore may, through proper exhaust pumps, produce the various degrees of rarefaction within the Tube.

TABLE No. 2.—*Showing the Horse-power required to produce the various degrees of rarefaction within the Tube, or the time within which the rarefaction may be produced with a power of 3,000 indicated horses exerted through the Exhaust Pumps; and the volume to be added for expansion of the air within the Tube. Diameter of Tube, 4 metres; length of Tube, 22 miles.*

Barometer in inches within the Tube, or tension of the atmosphere, reduced by the Pumps from 30 inches normal Pressure to :—	Time to produce the various degrees of rarefaction within the Tube by a power of 3,000 indicated horses exerted through the Pumps.	Volume for expansion to be added to the original volume of the air within the Tube, to produce the various degrees of rarefaction, also the volume to be displaced by any Pumps on Shore.
Inches Mercury.	Hrs. Mins. Secs.	Cubic feet.
29	0 0 11.78	541,800
28	0 0 49.10	1,122,300
27	0 1 56.00	1,745,800
26	0 3 36.62	2,417,300
25	0 5 56.46	3,142,400
24	0 9 1.54	3,928,000
23	0 12 59.10	4,782,000
22	0 17 55.22	5,711,000
21	0 25 37.22	6,733,800
20	0 31 46.18	7,856,000
10	5 2 55.34	31,424,100
0	Infinitely large.	Infinitely large.

From the above table it appears that the first few inches of rarefaction, or "differences of pressure," may readily and quickly be obtained, but that the power rapidly increases with an increased degree of rarefaction—for example, 3,000 effective horse-power on shore will produce a rarefaction within the Tube of 4 inches below the ordinary pressure of the atmosphere in less than 4 minutes (3 minutes 36 seconds), whilst to reduce the pressure to 8 inches below the atmosphere it would require nearly 18 minutes, during which the exhaust pumps would have to be worked without intermission with an effective power of 3,000 horses. Higher degrees of rarefaction will demand a power which increases still more rapidly. The pressure for working the trains at a rate of 20 miles an hour could readily be obtained within 4 minutes from the time of starting the exhaust pumps; but with a velocity of 30 miles an hour, the pressure for working the trains could not be obtained under 18 minutes; so that, by adopting exclusively the principle of expansion, a delay of 18 minutes would occur before the train could be started.

In these calculations, the cooling of the air as a consequence of its expansion was not taken into account, because it would only

have complicated the investigations without throwing additional light on the subject. The cooling of the air would favour the process of exhaustion, and the various degrees of rarefaction would be reached in practice a little sooner than shown by the figures of the table.

No. 8.

Propulsion by Compressed Air.

By compressing the air and increasing thereby its tension, its elastic force may be made to propel the train through the Tube. The difference between working trains by compression or by expansion, is this,—that with the former the pressures created by the pumps is immediately available, the pumps being close behind the train; with the latter, some time must always elapse before the tension of the air within the Tube has been reduced to the required degree, the pumps being 22 miles distant from the train. But whether compression or expansion be the means of propulsion, the figures of Table No. 1 will remain for either mode the same, although the readings as to barometer would be different.

Taking again a velocity of 20 miles an hour, a train would be worked through the Tube on the system of compression in the following manner:—A pressure of about 1 inch would set the train in motion—for, under the head of traction, we find the column would be $1\frac{1}{8}$ inch; as the train proceeded, the air in front of it would be pushed forward, and by degrees so much compressed that its tension would be high enough to discharge at the far end of the Tube all the air that the train may displace; at this point the normal condition of working will have set in, and the pumps would be now supplying air at a pressure of $4\frac{1}{2}$ inches above the atmosphere. Accordingly, in starting the train, the pumps would have to supply air at a tension of $1\frac{1}{8}$ inch above the atmosphere, or measured by a barometer, it would be $31\frac{1}{8}$ inches. As the train proceeded the pressure would have to be increased, until it became $34\frac{1}{2}$ inches, which having been reached, the pressure on the pumps would remain constant for the remainder of the journey. But although the pressure would be constant upon the pumps, it would be different along the whole length of the Tube. The normal condition of propulsion having set in, the pressure behind the train would be $34\frac{1}{2}$ inches, in front $33\frac{1}{8}$. As the train proceeded on its journey, the tension of the air surrounding the train would constantly be decreasing; half way the pressures would be $32\frac{1}{8}$ behind, and $31\frac{1}{8}$ before; and the train having reached the far end of the Tube, the pressures would be $31\frac{1}{8}$ behind and 30 inches in front, the latter being the tension of the atmosphere on the other

shore. The constant quantities are,—the difference of pressure at the two ends of the Tube, viz., $4\frac{1}{2}$ inches; the difference of pressure immediately in front and behind the train, viz., $1\frac{1}{8}$ inch; and the pressure under which the pumps would have to supply the air, viz., $4\frac{1}{2}$ inches above the atmosphere. Accordingly the resistance to be overcome by the pumps would be constant. The propulsion of the train would require, as before, 2,268 indicated horse-power during the time of passage, and the work of compressing the air distributed over the time of passage of 66 minutes would amount to another 154 indicated horse-power. The total expenditure of power in working the train through the Tube at a rate of 20 miles an hour, displacing goods at a rate of 12,000 tons daily, would therefore be 2,422 indicated horses.

The power for the same result of daily displacement of goods on the system of expansion would be 2,477 horses, viz., 2,268 for transmission, and 209 for the expansion of the air, the latter power being distributed over the time of passage of the train of 66 minutes.

The difference as to power of the two modes of propulsion is therefore small, being in favour of compression by 55 indicated horses. If, however, high differences of pressure were indispensable for working the traffic through the Tube, then the object could only be accomplished, properly and economically, by the system of compression. With small differences of pressure, it is immaterial which mode of creating the required pressures may be adopted for the propulsion of the trains.

No. 9.

Propulsion by combined action of Compression and Expansion.

It is desirable, however, to disturb the normal condition of the air as little as possible. If a pressure of four inches were to be produced, then the air would be least disturbed, if half of it were obtained by compression, and half by expansion, because it would only suffer a disturbance of two inches plus and minus from its original condition, the effect of these disturbances being much smaller than the effect of the total disturbance on either the positive or negative side.

The most economical and prompt way of working the trains through the Tube, on the Pneumatic system of propulsion, will therefore be to combine expansion and compression, forcing the air into the Tube behind the train, and withdrawing it in front of it. Working the trains in this way, other important advantages would be gained in addition, viz., 1st. The effects of heating and cooling of the air as a consequence of compression and expansion would neutralise one another. 2nd. The trains might be started

at either end without any delay whatever. 3rd. At each shore end of the Tube, only half the engine power would be required, because the whole effect to be produced would be equally divided between the establishments on each shore. 4th. Having arrangements for compression and expansion of the air on either shore, the traffic might be worked from one shore to and fro, during a temporary derangement of the machinery at the other, and, consequently, greater control over the traffic would be gained.

No. 10.

Starting the Trains.

The Tube will be prolonged on each shore about half a mile ; this length of the Tube will be commanded by two sluice or portcullis doors, made of wire netting and covered with india-rubber, one to be at the mouth of the Tube, the other half a mile from the first, seawards. Between these doors the trains will be formed, which will consist of about 100 waggons, shunted into position by ordinary engines. The train being ready, the door at the mouth would be closed, and that in front of the train would be opened, and the pumps of both the shore establishments may now be set to work. The train will be immediately started by the pumps supplying compressed air. About nine-tenths of the journey being completed, the supply of compressed air would be discontinued ; the exhaust pumps would now be drawing the train, assisted by the expansion of the compressed air within the Tube, until the train arrived at its destination.

During the propulsion of the first train, the second may be formed between the sluice doors, within which the preceding one was put together, having for this purpose previously closed the inner door. Upon the arrival of the first train, the second may be ready to start on its journey ; the sluice door in front of it would be opened, the compression pumps again started, and the second train would complete its journey like the first, and so on. It will be found convenient to work the traffic in one direction for several hours, but the direction may be changed at any time.

No danger could arise through mismanagement of the sluice doors. Mistakes in closing or opening at the right time would only prevent the train being started ; nor would it matter, if on the arrival of a train the doors were not opened, for the air between the door and the train would act as a most elastic cushion of several hundred yards length, and would gradually bring the train to a standstill ; and even if the door were to drop by accident right before the train, then the door would be broken through, without causing any other injury.

Engine Power and Pumps of the Establishments on Shore.

During the transmission of ordinary trains, the indicated power to be exerted through the pumps on each shore, would be 1,250 horses, making the total power for the transmission of the train 2,500 indicated horses. The engine-power of each establishment should be 1,500 nominal horse-power to be divided between two similar engines of 750 each, of which one to be wholly in reserve. The 750 nominal horse-power to be worked up to 1,250 for the ordinary traffic, and for the express traffic to 3,000 indicated horses; boiler power being provided accordingly.

For the ordinary traffic, the pressure between the two shore ends of the Tube would be measured by a column of mercury of 4.46 inches, of which 2.23 would be produced by compression, and 2.23 inches by expansion of the air. For the Express traffic the total pressure would be 8.21 inches, of which again half would be obtained by compression and half by expansion of the air.

The pumps would be cylinders of wrought-iron plating, about half an inch thick, 100 feet diameter and 50 feet stroke, forming bells immersed in water. At each station to be one pair of cylinders for compression and another for expansion of the air, to meet the ordinary daily traffic; a similar system of pumps to be kept in reserve. The cylinders of the pumps to perform the stroke with their axes in a vertical line, and the water into which they would be immersed to be in lieu of pistons. The cylinders would be raised by hydraulic power, and to equalize the variable pressure during the process of rarefaction, a number of hydraulic lifting rams would be employed within each cylinder, of which so many would be set to work as may be required to overcome the resistance for the time being. The cylinders of each pump to balance one another, one rising and the other falling, and *vice versa*.

THIRD SECTION.

No. 12.

Time of Completion.

The time of completion of the Channel Railway will in some measure depend on the support which the scheme may receive from the public, and upon the management and superintendence which might be insured during the construction of the works. But even with the required capital available, and first rate management, there is a minimum of time, which could not be further reduced without impairing the success of the works, and probably a maximum of time, which peculiar conditions of the bed of the channel might determine.

We will endeavour to ascertain these periods, and by taking the mean of the two, determine the time within which the Channel Railway might reasonably be expected to be completed.

Referring to No. 2 of the First Section of this Appendix, which is a description of the proceeding of building the Tube in deep water within the bell, it will be readily seen that one ring might be put together by the aid of the proposed machinery in one hour, provided all be properly managed. The parts of the ring having already been put together on shore, there can be no delay in repeating the operation by the aid of machinery, so powerful, that the weight of any one part ceases to be of any account.

The parts of the rings are heavy plates, which, however, in reference to the machinery and available power, may be placed and fixed with the same ease as common bricks in building an arch.

The caulking of the joints is, perhaps, the least rapid of all the various operations, but the joints may be readily taken in hand by a great number of workmen; for doing this operation quickly, it will probably be expedient to employ special caulking machinery.

At every third ring one pile, and at every sixth two piles should be sunk into the ground; or, if we assume the construction of one ring in one hour, then every third hour one pile, and every sixth hour two piles should be sunk. Upon a good foundation, such as stiff clay or coarse sand, the piles need not be sunk deeper than about 10 feet, which, by suitable machinery and the power on hand, could be readily accomplished in half an hour, so that under such circumstances the sinking of piles might keep pace with

the building of the Tube at the assumed rate. The progress would then be about 20 rings per day; allowing four hours daily for changing workmen, for rest at certain intervals, and so on.

At this rate of building the Tube the progress would be a mile a month, which for 21 miles length of the Tube in deep water would determine the minimum time for this portion of the work at one year and nine months.

The first and last half mile will require each about four months; the piles would be more numerous, and must be sunk deeper, and for about a quarter of a mile the building of the Tube would be confined to 12 hours daily. Moreover, experience must be gained in the construction of the first portion, so that the average progress would not be more than about one-eighth of that in deep water.

To prepare the machinery for constructing parts of the Tube, and the machinery and pumps for the supply of air and water, &c., &c., one year at least would be required. In the meantime the survey of the Channel on the proposed line might be made, the foundations prepared, and so on.

Accordingly, the minimum time would be—

1st. Preparing machinery, foundation, survey, &c.	1 year 0 months.
2nd. Starting and landing the Tube	8 months.
3rd. Building the Tube in deep water	1 year 9 months.
Total	<u>3 years 5 months.</u>

Or, say $3\frac{1}{2}$ years.

The possible maximum for the time of completion would be, under exceptional circumstances, about as follows:—Preparing machinery, foundations, and surveys, might require two years. The starting and the landing of the Tube would not be altered, because we have for these operations choice of ground, and accordingly there is no reason that it should exceed 8 months. The building of the Tube in deep water might, however, be retarded by unfavourable circumstances in the bed of the channel, which a detailed survey might bring to light. If it were a succession of depressions and elevations, which would require considerable length and depth of piling, and, perhaps, building the Tube upon curved lines, not more than about six rings might be constructed in 24 hours; not that the construction of the rings would require more time, but because their construction would depend upon the progress that might be made with sinking the piles. Under these circumstances, the progress of building the Tube in deep water would be about one mile in three months, and the total time required would be—

1st. Preparing machinery, foundations, survey, &c.	2 years 0 months.
2nd. Starting and landing the Tube	8 months.
3rd. Building the Tube in deep water	5 years 4 months.
Total	8 years.

The mean between these calculations would be about 6 years; but from all the information that can be obtained, the bottom of the channel appears to be even and uniform on the proposed line, and it is probable that the Tube may be completed from shore to shore in less than 5 years from the commencement of the works, by which time it may be ready to carry a large amount of traffic between England and the Continent.

No. 13.

Estimate.

In the construction of the Channel Railway, the principal cost will be the casting and fitting of the parts of the Tube, viz., the segments and rings, operations which will be carried out on shore.

The castings of the segments will at the present time be readily obtained in the quantity required at £5. 5s. per ton. These castings are all of one pattern, and are more simple, and may be more easily produced than large water pipes, which may be obtained in any quantity at the price named.

The labour per ton of the segments as castings is also less than that of large pipes; the castings will not cost more than five guineas per ton, and may be delivered on shore near Dover at £5. 10s. per ton.

The mechanical operations of planing, turning, boring, &c., will be amply covered by an allowance of 5s. per ton. We have shown in the First Section, No. 1, that with an establishment of half-a-dozen powerful lathes, about two dozen planing machines, and a dozen drilling and other tools, 600 tons of the Tube might be turned out daily, which, at 5s. per ton, would be an allowance of £150 per day for wages, wear and tear of tools, &c. The cast-iron construction of the finished rings will therefore, at the mouth of the Tube, cost, say, £5. 15s. per ton.

The wrought-iron construction of the Tube will consist of the skin, forming the inner surface of the Tube, of the shafting for the piles, and of the bolts. By far the largest quantity of wrought-iron will be the plates forming the skin, which, when finished, would be common plates bent to the inner radius of the Tube, and attached to it by a number of small screws. It is estimated that the wrought-iron construction will, on the average, be obtained at

£15 per ton. The weight of the iron construction for $20\frac{1}{2}$ miles of the proposed average section would be, per mile—

Cast-iron . . .	32,345 tons.
Wrought-iron . . .	2,270 tons.

For the first and last half mile, making together one mile in length, the weight of the construction would be—cast-iron, 48,517 tons; wrought-iron, 3,340 tons. The total weight of the iron construction from shore to shore, of $21\frac{1}{2}$ miles length, and its cost would therefore be—

Cast-iron, 712,000 tons, at £5. 15s. per ton,	£4,094,000.
Wrought-iron, 50,000 tons, at £15. per ton,	£750,000.

The building of the Tube from inside the Bell would, for the various operations of putting together the segments, sinking piles, caulking joints, laying rails and pipes, finishing the Tube, &c., require about 70 workmen, which, in three shifts, would be amply paid by £100 a day, or, during 300 working days, at £30,000 per annum. Assuming the Tube to be completed within 5 years, the cost of building it from shore to shore would be about £150,000.

The lead for caulking the joints would cost £160,000.

The brick lining would be covered by £130,000.

The temporary establishments on shore, machinery and workshops, with the temporary air and water-pipes and machinery within the Tube, the Bell, &c., would cost about £250,000.

The permanent establishments of machinery, steam-engines, air-pumps, &c., we estimate at £200,000; stations and approaches on each side of the channel, engineering expenses, steel rails, &c., would be covered by £650,000.

The total outlay in the construction of the Channel Railway would therefore be as follows:—

	£
1st. Construction of parts of the Tube on shore . . .	4,844,000
2nd. Building the Tube from shore to shore . . .	150,000
3rd. Lead for joints	160,000
4th. Brick lining	130,000
5th. Permanent establishments of machinery on shore . . .	200,000
6th. Temporary establishments, machinery, air and water-pipes	250,000
7th. Stations and approaches on each side of the channel, engineering expenses, steel rails, &c., &c. . .	650,000
8th. Interest during construction of works upon capital expended	600,000
9th. Contingencies	1,016,000
Total cost	<u>£8,000,000</u>

Probable Return upon the Capital.

It is difficult to estimate the probable return upon the capital. The amount of tonnage that might be carried between England and the Continent will, in all probability, only be limited by the power which may exist in passing the traffic through the Tube. Provision has accordingly been made to pass an amount of tonnage which would insure a satisfactory return upon the capital, at the ordinary charges of railway traffic.

There is no doubt that the expected quantity of goods for transmission across the Channel will be forthcoming at reasonable rates, but it is difficult to say what the charges per ton per mile might be beyond the ordinary railway charges, without checking the ready flow of business to the line.

As to the amount of tonnage that might be expected to be carried by the Channel Railway, it should be observed, that the business of the ports of Dover, Calais, Boulogne and Dieppe are no measure of the probable amount of traffic. The Channel Railway is not a local line between adjoining towns or ports, it is an exceptional line between England and the Continent. It will accordingly divert a large portion of the traffic of almost every one of the ports of England and France. Whether the sailing distance of a ship be 20 or 100 miles is not a material point, the principal expense being the shipping and unshipping of the goods, wharfage, docking, &c. : accordingly, the goods of either country do not at present seek the shortest route of transmission, but the most convenient and the cheapest. With the Channel Railway in a satisfactory working condition, these circumstances would be changed. The goods may then be conveyed between England and the Continent in the shortest possible time, without even a change of waggons.

As to the passenger traffic, its possible extent matters little in the estimate of the probable return, as the goods traffic alone would pay a handsome dividend. From a financial point of view it is of no consequence whether a satisfactory return be obtained upon the passenger or the goods traffic.

The increased facility and the great convenience of transmission which such a Railway would offer, will unquestionably largely increase the annual number of passengers across the Straits of Dover, and will also divert passengers from the North of England, from Belgium, the Netherlands, and so on. It is not a sanguine estimate to assume that one million passengers may be conveyed annually through the Channel Tube, considering that nearly half a million are at present crossing the Straits.

As to the charges that might be made upon the traffic per ton per mile, it is commonly accepted that the present expense of shipping and unshipping, wharfage, &c.—to say nothing of delay and injury to goods—amounts to about as much as the expense of conveying the same goods over an additional length of 100 miles of rail. The circumstances would therefore be somewhat on a par, if the charges of the Channel Railway were about four times as great as those of ordinary lines; but then, no material advantage would be gained by the transmission of goods by this route, and the ready flow of the traffic might be checked. It is quite possible, however, that double the ordinary Railway charges might be made upon this exceptional line, and yet as many passengers and as great a quantity of goods for transmission, as the Tube might be capable of conveying, might be obtained.

To indicate the nature of the probable return, we will assume only ordinary railway charges upon first-class goods, such as cotton, wools, manufactured goods, silks, leather, wine, spirits, chemicals, grain, corn, dyewoods, earthenware, timber, Manchester packs, and the like; at, say $2\frac{1}{2}d.$ per ton per mile on the average, for 24 miles length of railway, or 5*s.* per ton for the whole distance. The Channel Railway may readily carry 4,000,000 tons of goods per annum, which at 5*s.* per ton would amount to £1,000,000 return by the heavy traffic alone.

The charges for the conveyance of parcels, bullion, mails, &c., would more than cover the comparatively small working expenses of the line, which would not exceed £150,000 per annum; so that a net return of about £1,000,000 would be available upon a capital of 7, or perhaps 8 millions sterling, without taking the passenger traffic of the line into consideration.





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BOND

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